Marmousi-2: an updated model for the investigation of AVO in structurally complex areas

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Summary

We have created an elastic version of the IFP Marmousi model for use in AVO analysis in the presence of complex structure. The model is larger, includes larger offsets, lies in deeper water, includes surface streamer, multicomponent OBC and VSP acquisition, and contains more hydrocarbons than its predecessor. In addition to AVO analysis, we believe these data will be suitable for calibrating emerging technologies including converted wave tomography and vector seismic processing.

Introduction

The application of AVO is taken for granted in relatively simple structural areas, and it has been shown to be very useful. However, in structurally complex areas there remains some doubt as to whether it is applicable due to the various imaging problems and amplitude variation caused by effects such as focusing and defocusing. This study details the creation of a new synthetic model and dataset that will enable this to be investigated.

Seismic modeling is used as an aid to understanding problems seen in real data, and to assist in the design of acquisition programs for optimum subsurface illumination. The resultant synthetic seismic data can be used to validate and calibrate new processing methodologies. A common goal of geophysics is to image real data, but it is important to calibrate imaging algorithms on synthetic data where the earth model (the solution) is precisely known. In the real world the earth model is not known and it becomes impossible to test the efficacy of algorithms.

AVO analysis is limited by the quality of the input prestack gathers. Commonly, and increasingly routinely, seismic data is migrated prestack (in time or depth) with the resultant common image gathers (CIGs) forming the input to AVO analysis. The quality of the AVO response is therefore extremely dependent upon the correct migration positioning of the signals and the associated amplitude. In an ideal case “true amplitudes” are recovered across all offsets. Due to many limitations it may be more reasonable to expect only relative amplitude preservation rather than true amplitude preservation.

Although modeling has been used extensively to verify geophysical observations and calibrate algorithms, there are few models and synthetic datasets widely available to the industry. Of the handful of models available none are ideal for testing AVO in a structurally complex setting. However, one very commonly used 2D model, the Marmousi model (described by Versteeg, 1994) is structurally well suited to this task. The original Marmousi model has been one of the most successful models in the history of geophysics, and is still being used to calibrate imaging algorithms, nearly 14 years after its generation. This model however only contains a single gas and oil accumulation, which is located under structure; the trap itself is a simple anticline. The corresponding dataset, although created using wave equation modeling, is acoustic and therefore cannot contain a correct AVO signature.

The primary purpose for the creation of the dataset will be the analysis of AVO in complex structural areas. However, the data itself should be useful for a multitude of calibration and testing procedures, including the evaluation and calibration of migration algorithms (including amplitude preservation), velocity estimation methods, multi-component and VSP processing methods, elastic inversion methods, multiple suppression methods, *etc.*

Definition of the Marmousi-2 model

The new model, called Marmousi-2, is an extension to the original Marmousi model, and attempts to add to the model without taking away any of the qualities that have made it so useful. The model has been upgraded in the following ways:

- Model length has been extended from 9.2 km to 17 km;
- More hydrocarbons have been added in structurally simple and structurally complex areas;
- Stratigraphic features, including channels, and a zero P-wave impedance layer were added; and
- The model has been placed in approximately 500m of water, making the resultant data suitable for OBC methods.

The extension of the Marmousi-2 model has been done in a manner consistent with the regional geology but with attempts to reduce the structural complexity away from the central area (Figure 1a)), thereby providing a dataset that possesses both simple and complex areas for AVO calibration.

Elastic wave modeling methods require shear wave (S-wave) velocities in addition to the compressional (P-wave) velocities and densities for each layer. The P-wave velocities were preserved from the original model, with the exception of the salt, which was reduced to 4500 m/s. The

P-wave velocity was then used as the baseline from which to derive the remaining two properties. Firstly, the layers were assigned a lithology consistent with the original model. The section is primarily composed of shale units, with occasional sand layers, while the core of the faulted area is an anticline that is composed of marl. An unconformity and a partially evacuated salt layer separate the marls from the deeper anticlinal units, which are also mostly shales with some sand, as shown in Figure 1b). From this information the shear wave velocity and density can be synthesized using industry standard transforms. We used the Greenburg and Castagna (1992) transforms for obtaining S-wave velocity from P-wave velocity, and Castagna *et al*'s (1993) transforms for obtaining the density from the P-wave velocity.

Appropriate mixing models and effective medium theory were used to create the properties of the marl layers given that it is composed of 70% shale and 30% limestone. The material properties are shown on Figure 1 c)-e).

A series of hydrocarbon layers was created in the structural model. These are shown as red (gas) and green (oil) on Figure 1b). They are distributed within the complex faulted zone at different depths, and also in the simple structure at the flanks. These hydrocarbons layers vary in their size, shape, structural complexity, and content. Gas and varying GOR oil were introduced using standard fluid substitution techniques.

The model contains two transitional layers under the deep waterbottom. These layers exhibit a Vp/Vs ratio of 4:1 and 3:1, reducing the hard waterbottom effect. The ratios are consistent with soft modern sediments.

The model also contains a layer with units that should not be detectable by P-wave data alone. The units have identical P-wave velocity and density values to the surrounding layers so that there is no P-wave impedance. We modified shear wave values from the transform results to ensure small shear wave impedance contrasts.

Synthetic Data Acquisition

Elastic and acoustic shot records will be acquired over the model with frequencies up to 55Hz. Figure 2 shows the shot records for a test shot over the center of the model. Key aspects of the acquisition include the following upgrades:

- Three components (pressure, vertical velocity, and horizontal velocity) will be recorded on simulated streamers, OBC, and a series of VSP positions; and
- Offsets have been extended from ~2.5 km to greater than 9 km, comparable with modern marine capabilities.

Massively parallel computers at Lawrence Livermore National Laboratory will perform the calculations. The data will be made available to any interested parties in various formats. The model horizons and material properties will also be available for modification by future researchers.

Conclusions

We have generated an updated elastic version of the IFP Marmousi model for distribution to the international geophysical research community. In addition to shot gather synthetics useful for AVO, vector imaging, and converted wave tomography algorithm calibration, we have released the model grids, horizons, and layer definitions for those who wish to improve upon our modeling effort.

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Marmousi-2

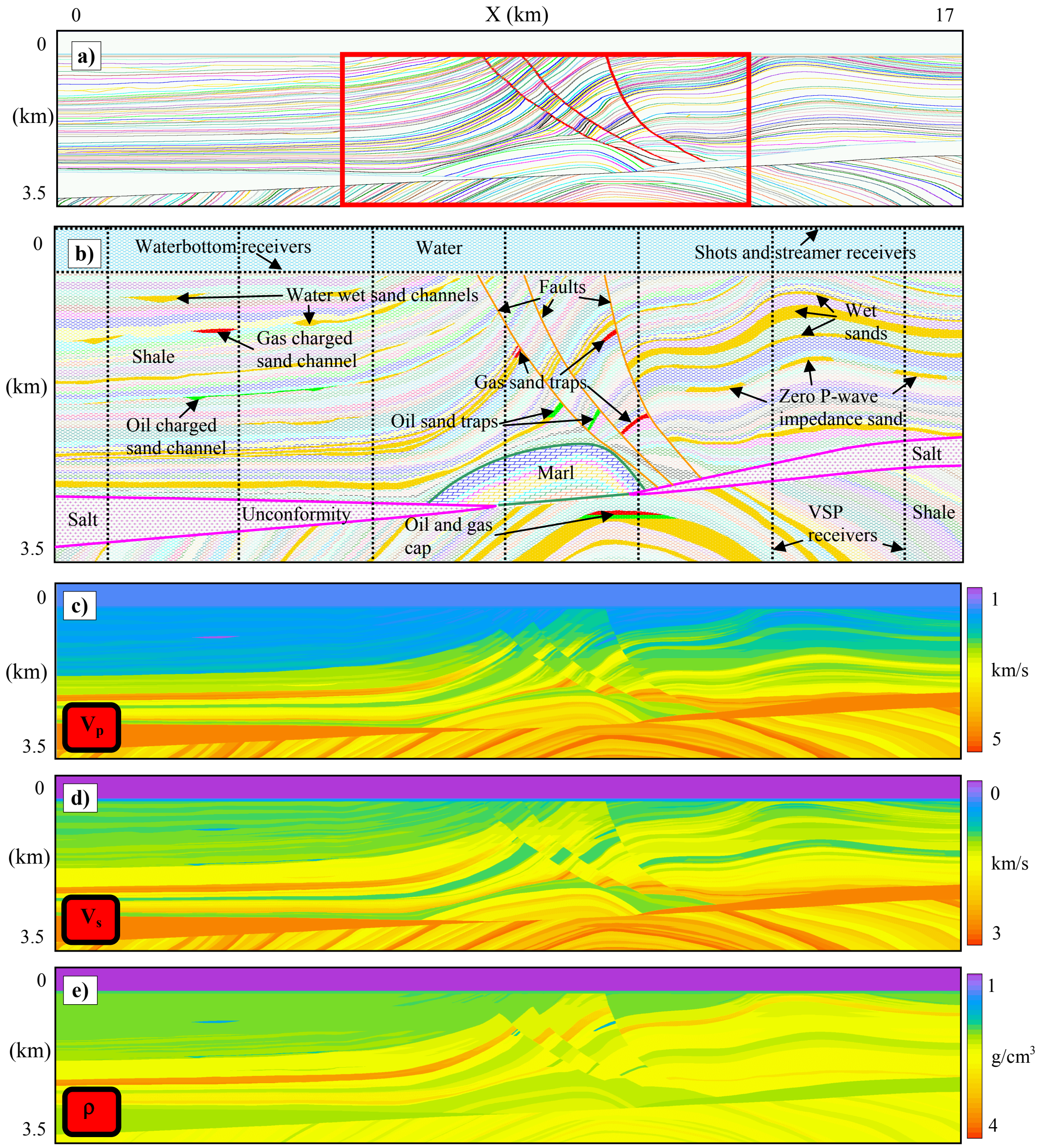

Figure 1 The Marmousi-2 model. a) model horizons, original Marmousi model size shown as red rectangle, b) lithology and model features including the location of hydrocarbons and the recording surfaces, c) P-wave velocity, d) S-wave velocity, and e) density. a),c),d), and e) are to scale, b) has a vertical exaggeration of x2.

Marmousi-2

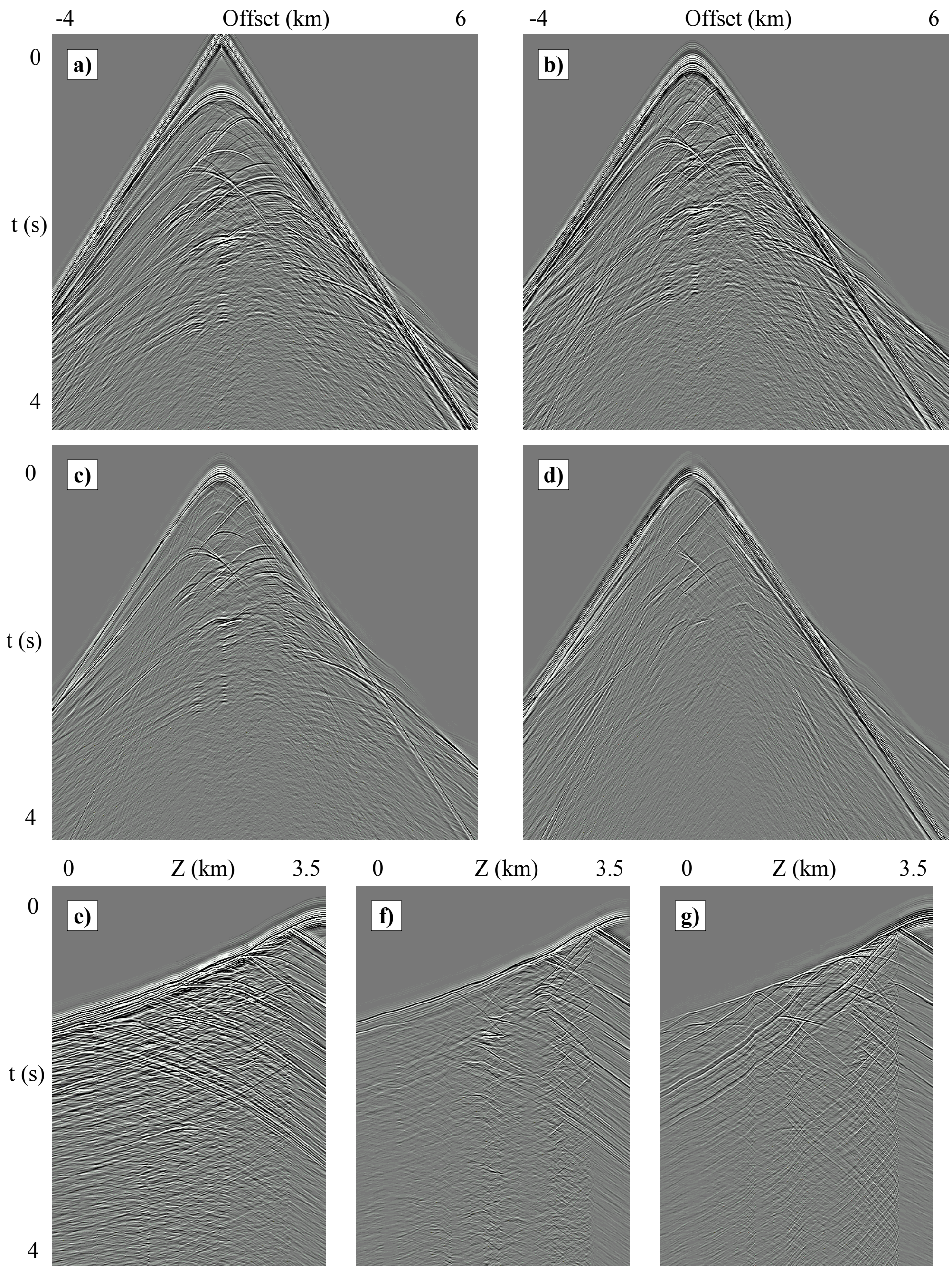

Figure 2 Synthetic seismograms from a test shot at x=9 km. a) streamer pressure, b) waterbottom pressure, c) waterbottom vertical velocity (Vz), d) waterbottom horizontal velocity (Vx), e) ,f), and g) are records from a VSP at an offset of 0.5 km; e) pressure, f) Vz, and g) Vx.